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Benefits of meteorological services: evidence from recent research in Australia

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This report is a summary of the methods and findings of a research project that evaluated the social and economic benefits of meteorological services in Australia. The meteorological services evaluated were the basic public weather services and several specialist user-pay and commercial services used by business firms in several sectors of the national economy. Overall, the results indicated that the quality of the selected services was high. In addition, the benefits of these services were extensive, resulting in high benefit–cost ratios.

1. Introduction

Weather- and climate-related natural disasters in Australia are frequent and often very costly. This has therefore led to a perennial interest in use of weather and climate information to manage adverse effects of these natural hazards. The major provider of weather and climate information in Australia is the Bureau of Meteorology (BoM). BoM is responsible for the collection, storage and archival of weather and climate data for use by present and future generations. It is also involved with free international exchange of meteorological information and other services administered by the World Meteorological Organization (WMO) based in Geneva, Switzerland. The extent of the services provided by BoM is summarised in its 1994–95 Annual Report, which defines the objectives, subprograms and components of activities undertaken by the Bureau based on the programme budgeting approach used by the public service in Australia and other countries. This programme budgeting approach is described in Table 1 and is based on four objectives: climate record, scientific understanding, Australian community welfare and international cooperation (WMO-related activities).

In the current era of increasing trends towards privatisation and corporatisation of 'traditional' government services, BoM has been under some pressure to reduce costs of operation and to justify any major upgrades of its services and equipment based on detailed benefit–cost analysis. In response to this development, BoM has been interested in demonstrating the economic and social benefits of services it provides to the general public, industries and organisations. The Australian Research Council sponsored a collaborative research project between Macquarie University and BoM to identify and estimate social and economic benefits of meteorological services provided by BoM. The objectives of the three-year research project were as follows:

(a) to establish methods for the assessment of the economic and social benefits of services provided by BoM;
(b) to assess the economic and social benefits of selected services at the Regional Office of BoM in New South Wales; and
(c) to assess the economic and social benefits of selected services provided by BoM from other Regional Centres.

Eight subprojects were undertaken in development of appropriate economic methodologies, evaluation and establishment of benefits of basic public weather forecasts and warnings for householders, aviation weather services, an enhanced weather service for agricultural producers, public weather and climate services for the

Table 1. *Programme budgeting structure of the Australian Bureau of Meteorology indicating its four main objectives, subprograms and component activities*

Objective	Subprogram	Component
Climate record	1. Monitoring and prediction	Observations Engineering Communications Analysis and research
Scientific understanding	1. Scientific development	Pure research Applied research Supporting R & D
Australian community welfare	1. Weather services	Public weather services Severe weather services Marine weather services Aviation weather services Defence weather services Special weather services
	2. Climate services	Climate data bank Climate data service Climate monitoring service
	3. Consultative services	Met. advisory service Special investigations
	4. Hydrological services	Water resources assessment Flood warning service Hydromet advisory service
International cooperation	1. International activities	International activities

mining industry and tropical cyclone warning services for both tourism (hotel operators) and homeowners. The subprojects cover geographical areas mainly in New South Wales and Queensland to meet the terms of reference of objectives (b) and (c). A summary of the subprojects based on the method of analysis, the sector involved and geographical coverage is provided in Table 2. This paper is organised as follows: firstly, the eight subprojects are each briefly discussed, starting with the first subproject which deals with identification of methods to establish the economic and social benefits of meteorological services; secondly, the results of the seven specific studies are compared in a discussion section with emphasis on the quality of the various services derived through users' surveys. The conclusions and references are then reported at the end of the paper.

2. Methods for evaluating benefits of meteorological services

The first of the eight subprojects was the establishment of methods to determine the economic and social benefits of meteorological services in Australia (research objective (a)). No one single methodology could deal with the requirements of measuring benefits of the varied services of BoM. This is partly because the services of BoM are used by all 108 Australian Bureau of Statistics classified economic sectors of the economy as inputs in their production processes. They are also used by households as consumption goods since the public weather services provide personal convenience to individuals for their day-to-day living and also provide them with personal safety information about weather-related natural hazards. As a starting point, valuation of benefits of meteorological services depends on two important economic concepts: indivisibility and non-exclusiveness (Randall, 1981). A good is *indivisible* (or is considered non-rival in consumption) if its use by one individual does not reduce its availability in terms of the quality and/or quantity of the service to others. A good is *non-exclusive* if individuals cannot be excluded or it is very difficult to exclude others from using the good. Based on the economic concepts of indivisibility and non-exclusiveness, the services of BoM can be classified into four groups:

(a) *Indivisible (non-rival) and non-exclusive goods*, often called 'public' or 'collective' goods such as basic public weather services and tropical cyclone warning services, which are freely accessible to all individuals through the mass media. This group also includes weather and climate data collection and archival services, as well as international public goods, such as freely exchanged meteorological data among member countries of WMO.
(b) *Indivisible (non-rival) and exclusive goods* such as terminal aerodrome forecast services at major international airports in Australia used by international airlines flying to Australia. These goods require users to pay some fees but use of the goods by one

Table 2. *List of subprojects by sector of enquiry, economic method employed and the time period the studies were undertaken*

Sector	Survey of users of weather and climate services to estimate aggregate industry benefits and quality of services based on quality attributes of information	Simulation modelling of use of weather information by business firms to estimate benefits	Econometric analysis of cost and/or income of business firms or industry to reveal benefits of weather and climate services	Contingent valuation technique to estimate the value of underpriced and/or non-market weather and climate services
Aviation		Subproject 3 (1994–95)	Subproject 4 (1994–96)	
Agriculture	Subproject 2 (1994–96)			Subproject 2 (1994–96)
Mining	Subproject 5 (1995–96)			Subproject 5 (1995–96)
Homeowners	Subproject 7 (1994–96)			Subproject 7 (1994–96)
Tourism			Subproject 6 (1994–96)	
General public (householders)	Subproject 1 (1995–96)			Subproject 1 (1995–96)

individual does not reduce the quality and quantity of the service to other individuals.

(c) *Divisible (rival) and non-exclusive goods* such as services dealing with recording of visually detectable weather events for which the number of weather stations recording these events in Australia and other countries has been declining. This implies that future generations will not have access to certain types of data available to the present generation. In addition, automation of weather recording using satellites sometimes lead to the non-recording of certain events which are more easily observed and recorded by humans. Such automated recording of visually detectable events appears to contribute to the divisibility of certain services as would appear to future generations of weather and climate information consumers who are likely to have less information on several visually detectable events.

(d) *Divisible (rival) and exclusive goods,* often called 'private or market goods', such as specialist services supplied to the mining industry for exclusive use by selected companies which pay commercial market-based rates for those services.

Given this background, the determination of economic benefits of the Bureau's services required application of research methods in applied economics such as environmental and resource economics, production economics, economics of information, economics of risk and uncertainty and welfare or normative economics. 'Social' or non-economic benefits derived from use of meteorological services (especially the public weather services) are usually difficult to value in economic terms. They are more likely to be expressed in non-monetary values, for example through the use of social indicators such as the reductions in weather-related human fatalities due to cold snaps, heat waves, tropical cyclones and aviation accidents from use of improved weather services. Qualitative listing of intangible benefits of meteorological services such as the reduction of anxiety and fear from severe weather events can also be expressed. The details of the methods used are fully described in recent issues of this Journal (Anaman *et al*., 1995; Anaman & Lellyett, 1996a,b; Leigh, 1995). The results and summary reports of the specific studies are discussed below.

3. Contingent valuation study of the public weather service in Sydney area

This subproject involved a survey of householders in the Sydney metropolitan area to evaluate the basic public weather forecasts and warnings produced by BoM. The full published report of this study is described by Anaman & Lellyett (1996c). The major aim of the subproject was to determine the economic value householders attach to the basic public weather service when the service was used as a consumption good. The economic value of the service when used as a consumption good was established using the contingent valuation technique whereby respondents were requested to indicate the maximum amount they would be willing to pay to have access to the service (rather than be without it). The quality of the service was also evaluated based on several attributes of good information. Five hundred and twenty-four members of the general public were randomly selected. The respondents were contacted by telephone in January and February 1996 and asked a number of questions related to public weather

forecasts and warnings. The average interview lasted between three to six minutes

The results indicated that the average annual willingness-to-pay for the service for all respondents was about 24 Australian dollars (A$), or A$2 per month. This was slightly over four times the current annual cos per taxpayer of providing the service (A$5.8). Five-eighths (62.5%) of respondents indicated that they would *not* be willing to pay for the service even though most of them considered it an essential service for society. Householders not willing to pay for use of the service tended to be older people or those who used it infrequently. Overall, respondents considered the service of good quality and modestly useful for their day-to-day activities. About 9% of householders also used the public weather service for business purposes in addition to using it for day-to-day living purposes. Householders working in the construction industry constituted the largest subgroup of users who used the service for business purposes, making up about 21% of the group.

4. Evaluation of the Cottonfields Weather Service

This subproject was a study of producers' evaluations of an enhanced weather information service called the Cottonfields Weather Service produced by the Special Services Unit of BoM for areas in New South Wales and Queensland. The study involved a random sampling survey of members of the Namoi Cotton Co-operative, one of the largest cotton producing groups and the largest cotton processor in Australia. The Cottonfields Weather Service provides, at some cost to producers, the latest weather forecasts and information for a particular locality which are more detailed than the information obtained from the basic public weather service provided freely through the mass media. Access is through a phone facsimile machine. Producers' assessment of the enhanced weather service was based on numerical scoring (derived from a uniform scoring scale) of key quality attributes of information for managerial decision making such as timeliness, ease of understanding, accuracy and overall usefulness. About 51% of the members of the Co-operative had adopted the service at the time of the survey. Users generally considered the service of high quality, useful and effective.

4.1. Economic benefits

The average annual willingness-to-pay value (WTP) for the service at the time of the survey (a drought period) was about A$223. In addition, producers were willing to pay on average A$260 annually for the use of the service during a period of good rainfall. These two WTP values were higher than the estimated average costs incurred by producers for accessing the service based on facsimile charges, which were about A$190 per producer. Change in producers' surplus (aggregate gross producer benefits) derived from producers' responses were based on an estimated average 1% cost reduction in production of raw cotton when using the service. The analysis indicated that the average annual aggregate gross benefits were about A$397 150 for cotton production only. The total annual costs incurred by cotton producers for the use of the service were A$31 590. Hence the benefit–cost ratio of the service (for cotton production only) from a national perspective was 12.6.

4.2. Social or 'non-financial' benefits

The majority of the users indicated that it provided them with some non-financial benefits. About 36% of the users reported that the service assisted them in their general household planning and decision making. Planning of outdoor and recreational activities was identified as the second most important non-financial benefit of the service (14% of users) followed by planning social events (9%), planning family holidays (9%) and more free time (9%) on equal scales of importance. Non-financial benefits appeared to be oriented towards general household planning, leisure activities and work time savings. About 9% of users indicated that the service provided no non-financial benefits (Anaman & Lellyett, 1996a,b).

5. Evaluation of benefits of terminal aerodrome forecasts for Sydney airport

A cost–loss ratio-based decision model was adapted to Qantas Airways Limited's alternate fuel uplift decision. Qantas' current fuel policy requires that additional fuel called *alternate fuel* equivalent to one-hour flying time be added to the total fuel load if the weather conditions contained in the terminal aerodrome forecasts (TAFs) at the destination airport are forecast to be severe. If the weather conditions are forecast not to be severe, the pilot before take-off may choose not to add the alternate fuel to the total fuel load. This discretionary policy is not available to most airlines since the alternate fuel is automatically added to the total fuel load regardless of the predicted conditions at the destination airport. The economic value of TAFs in terms of fuel savings to Qantas is therefore dependent on the accuracy of TAFs. Forecast accuracy measures were derived from TAF verification data held by the BoM; relationships between TAF accuracy, expected airline operating cost, and the value of the forecasts to the airline were determined. The analysis was extended to consider indirect and external costs, and the concept of a socially optimal level of accuracy was examined. Details of the findings of this study were published in this journal recently (Leigh, 1995). Briefly, the major outcomes of the study were as follows.

5.1. Economic benefits of TAFs

The benefit to Qantas of a 1% increase in the average accuracy of TAFs for Sydney Airport was estimated to be over A$1.2 million per year for international routes for 1993. Although average TAF accuracy was high and a 1% increase represented a substantial improvement, this result indicated that even small improvements in accuracy would produce sizeable benefits for the whole aviation industry. The annual value of the Sydney Airport TAF service to Qantas, based on international routes only, was estimated to be at least A$6.86 million for 1993. Extending the results nationwide, the annual savings were about A$16 million based on Sydney handling about 43% of Qantas' international flights to and from Australia. This value was also shown to be greater than the annual charge levied on the airline by the government for all aviation weather services in Australia of about A$6 million. Qantas' current risk-neutral alternate fuel policy produces lower expected costs than the alternative risk-averse policy of always carrying alternate fuel.

5.2. Social or 'non-economic' benefits of TAFs

Non-economic benefits were reported in the study but only the value of passenger time savings was estimated. Non-economic benefits not quantified included reduction of inconvenience and anxiety to passengers due to reduced diversions and the reduction of greenhouse gas emissions.

6. Econometric analysis of effect of aviation weather forecasts on operating costs of Qantas Airways Limited

This study involved an econometric analysis of the effect of aviation weather forecasts on operating costs of Qantas Airways Limited for its international operations. The subproject was conducted based on annual data from 1971/72 to 1993/94. The weather forecasts evaluated were the terminal aerodrome forecasts and the upper atmosphere wind forecasts for the entire globe available to Qantas Airways Limited and other international airlines. Initially, a total cost function model based on economic theory of the firm was developed to capture the effect of aviation weather forecasts on total costs. Because of the high aggregation of the annual data, a single variable, the output of the airline, accounted for virtually 100% of the variation in the total cost, rendering the model inappropriate for such analysis. An alternative approach involving a component of total cost of direct relevance to weather forecasts was considered. Given the important role of weather forecasts in deciding the amount of fuel to carry for international flights, a total fuel cost function approach provided a means of establishing the value of weather forecasts. Hence, long run and short run total fuel cost functions of the airline were estimated by multiple regression techniques with total fuel cost as the dependent variable. Independent variables were price of aviation fuel, output of the airline, capitalisation of the airline measured by the depreciation of aircraft, alternate fuel policy concerning use of TAFs and quality of upper atmosphere wind forecasts. The short run fuel cost function involved use of first differences of economic variables and a pulse dummy variable for fuel policy change involving TAFs that occurred in 1985. This fuel policy change allowed pilots the discretion not to add alternate fuel to the total fuel load if the weather forecasts contained in the TAFs at the destination airport are not severe. Before 1985, the alternate fuel load was added to the total fuel load regardless of the predicted weather conditions at the destination airport.

6.1. Economic benefits

Preliminary results reported by Anaman & Lellyett (1997) indicated that the airline fuel consumption was strongly related to the price of aviation fuel and airline output as expected from economic theory of demand. In addition, increased capitalisation involving the acquisition of more fuel-efficient planes led to a reduced fuel consumption. The abandonment by the airline of mandatory requirement for pilots to carry alternate fuel in 1985, in favour of carrying such extra fuel based on weather forecasts, saved between A$27 to A$42 million annually in reduced fuel consumption in 1993/94 dollars. These estimates were in line with expectations by the airline that the benefit of the change was between A$20 and A$80 million. The effect of upper atmosphere wind forecasts on airline fuel consumption was not established, possibly due the high aggregation of the annual data which might have masked the effect of wind forecasts on fuel consumption.

6.2. Social or 'non-economic' benefits

Based on the A$42 million annual fuel savings from the use of TAFs, representing about 6% reduction in fuel consumption from use of TAFs for the 1993/94 financial year, about 120 million litres or 95 256 tonnes of fuel would be saved annually. Commercial aircraft produce about 3.2 tonnes of carbon dioxide (CO_2) per tonne of fuel consumed (Nusser & Schmitt, 1990). The annual fuel savings were equivalent to about 304 820 tonnes less CO_2 in the atmosphere.

6.3. Quality of upper atmosphere wind and temperature forecasts and TAFs

The quality of upper wind and temperature forecasts measured by root mean square errors (comparison between predicted outputs based on high resolution

Table 3. *Estimated average yearly root mean square errors of upper temperature and wind forecasts at 250 hPa pressure level measured against radiosonde observations over the Australasian region of the globe from 1972/73 to 1994/95*

Financial year	Temperature (°C)	Wind speed (m s^{-1})
1994/95	1.92	8.60
1993/94	1.82	8.47
1992/93	1.98	8.92
1991/92	2.00	9.22
1990/91	1.98	9.31
1989/90	1.97	9.26
1988/89	2.16	9.62
1987/88	2.38	13.29
1986/87	2.43	13.52
1985/86	2.59	14.80
1984/85	2.68	14.83
1983/84	2.71	15.30
1982/83	2.79	14.62
1981/82	2.74	15.23
1980/81	2.83	14.62
1979/80	2.88	15.13
1978/79	2.90	16.04
1977/78	3.06	17.02
1976/77	3.08	17.12
1975/76	2.93	17.61
1974/75	2.79	16.85
1973/74	2.91	16.57
1972/73	3.11	16.96

global meteorological models and observed data) from 1972/73 to 1993/94 *over the Australasian region* are summarised in Table 3 and illustrated in Figures 1 and 2. There appeared to be a general improvement of both forecasts over this period. Regression analysis of the log of root mean square errors for both upper atmosphere variables on a time trend indicated that the coefficient of the time variable was negative and statistically different from zero confirming improvement of these forecasts.

Statistical analysis based on average results for Sydney, Melbourne, Brisbane and Perth airports from Table 4 indicated that while the overall accuracy of TAFs had been consistently high, there had not been a significant improvement in the quality either measured by the percentage of correct forecasts (which averaged about 88%) or the proportion of no alternate forecasts issued by BoM that turned to have required alternate fuel (which averaged about 1.8%). The latter represented the possibility of diversions based on Qantas' current fuel policy. (For full details see Anaman, Lellyett & Avsar, 1997.) The accuracy of TAFs is illustrated in Figures 3(*a*) and 3(*b*).

7. Evaluation of use and benefits of public weather and climate services by the mining industry in Queensland

This study evaluated the use and benefits of publicly provided weather and climate services by the mining industry in Queensland. It involved a survey of mining companies in Queensland about their use of publicly funded weather and climate services produced by BoM using the mailing-in-method of survey. A pilot survey of two mining companies in Queensland was completed at the end of January 1996 undertaken jointly with the Queensland Mining Council based in Brisbane. The final survey started in March 1996 and ended in September 1996 with 67 out of 85 members of the Queensland Mining Council responding to the survey, a response rate of 79%. In addition, visits were made to two mines in the Newcastle area (an open cut mine and an underground mine) in August 1995 to study use of weather services by mining companies as an information gathering exercise to develop the questionnaire for the interview.

Economic benefits of the public weather and climate services to the mining industry were ascertained through:

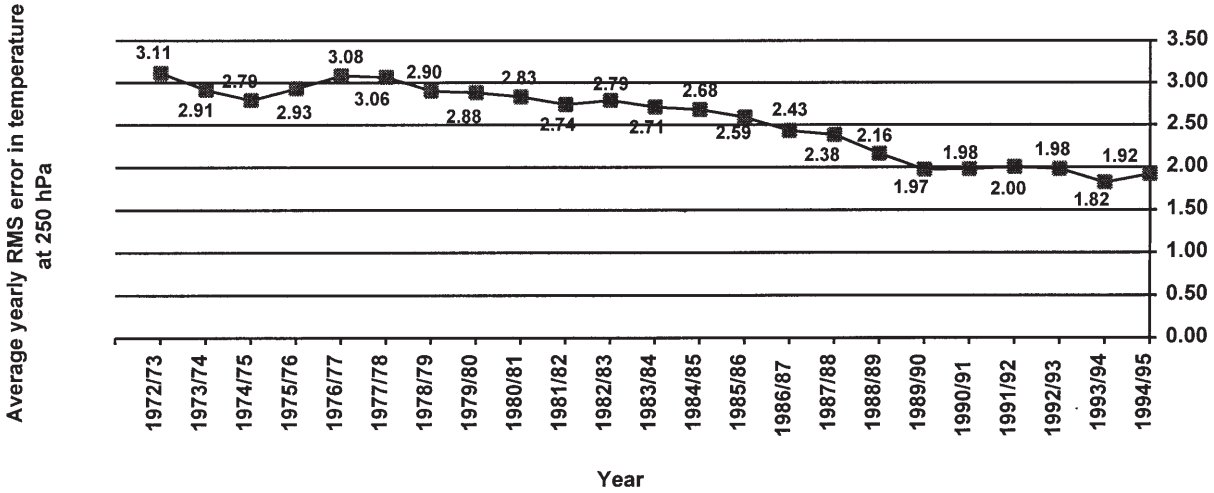

Figure 1. *Illustration of the decline in the average yearly root mean square (RMS) errors of upper temperature forecasts at the 250 hPa level measured against radiosonde observations over the Australasian region of the globe from 1972/73 to 1994/95.*

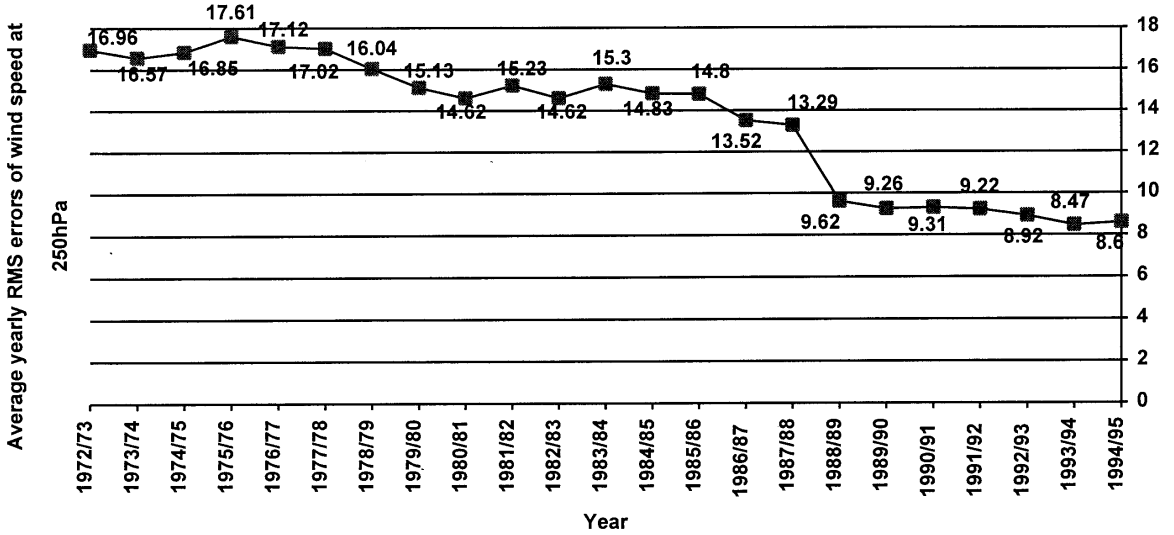

Figure 2. *Illustration of the decline in the average yearly root mean square (RMS) errors of upper wind forecasts at the 250 hPa pressure level measured against radiosonde observations over the Australasian region of the globe from 1972/73 to 1994/95.*

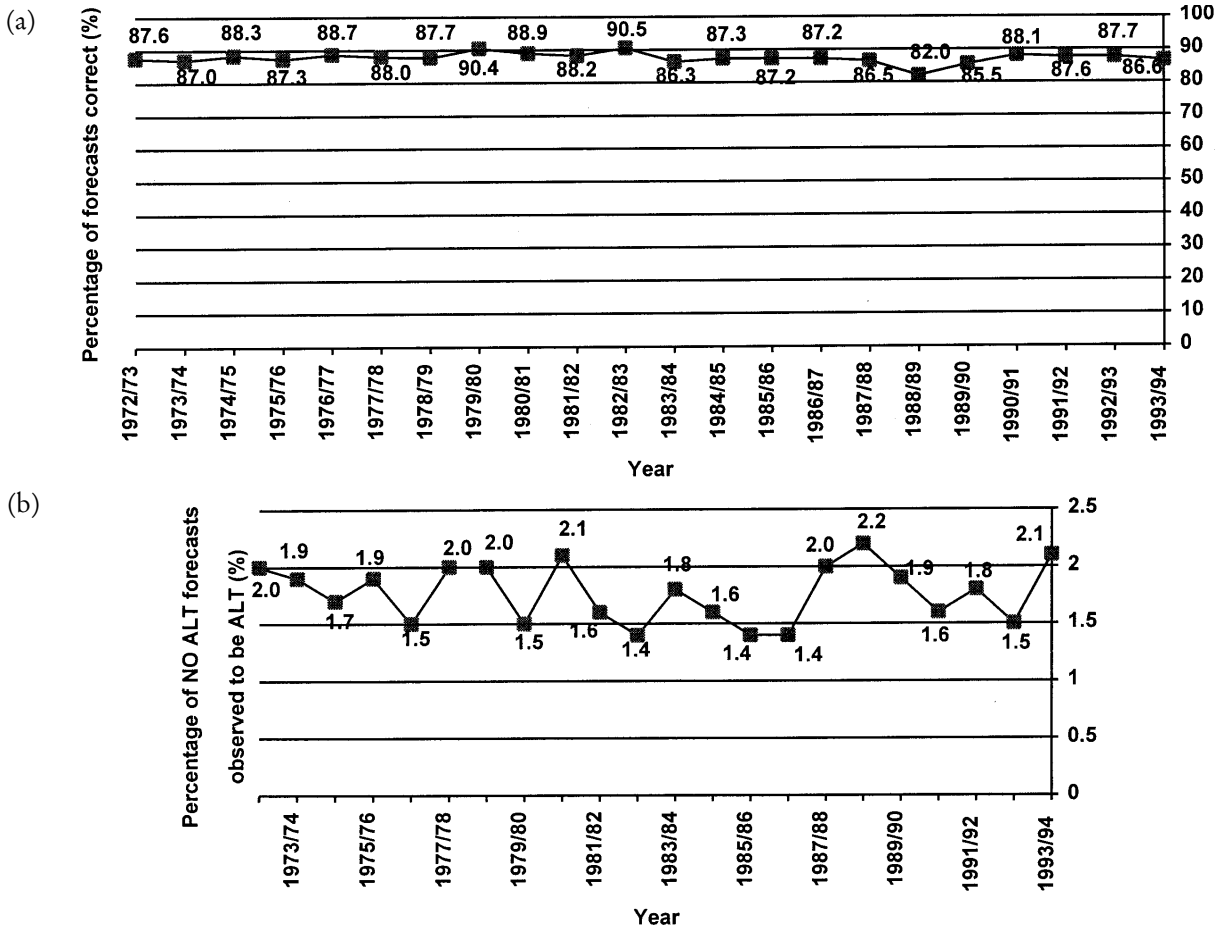

Figure 3. (a) *Diagrammatic representation of the average annual accuracy of TAFs measured by the percentage of all forecasts correct for Sydney, Melbourne, Brisbane and Perth from 1972/73 to 1993/94.* (b) *Diagrammatic representation of the average annual accuracy of TAFs measured by the percentage of no alternate fuel required forecasts which were to have required alternate fuel for Sydney, Melbourne, Brisbane and Perth from 1972/73 to 1993/94.*

(a) the reduction in weather-related production losses made possible from use of weather and climate services, and
(b) the contingent valuation method whereby managers were requested to indicate the maximum amounts of money that they would be willing to pay (WTP) to use the services rather than be without them.

Preliminary results indicated that mining firms on average would be willing to pay about A$5346 annually to have access to public weather and climate services rather than be without them. The perceived quality and frequency of use of services were the significant factors influencing the WTP for the weather and climate services. The average frequency of use of basic public

Table 4 *Estimated average annual accuracy of TAFs measured by (a) the percentage of all forecasts correct and (b) the percentage of no alternate fuel required forecasts which were observed to have required alternate fuel for the four major Australian international airports (Sydney, Melbourne, Brisbane and Perth) from 1972/73 to 1993/94*

Financial year	(a) % of forecasts correct	(b) % of no alt. forecasts observed to be alt.
1993/94	86.6	2.1
1992/93	87.7	1.5
1991/92	87.6	1.8
1990/91	88.1	1.6
1989/90	85.5	1.9
1988/89	82.0	2.2
1987/88	86.5	2.0
1986/87	87.2	1.4
1985/86	87.2	1.4
1984/85	87.3	1.6
1983/84	86.3	1.8
1982/83	90.5	1.4
1981/82	88.2	1.6
1980/81	88.9	2.1
1979/80	90.4	1.5
1978/79	87.7	2.0
1977/78	88.0	2.0
1976/77	88.7	1.5
1975/76	87.3	1.9
1974/75	88.3	1.7
1973/74	87.0	1.9
1972/73	87.6	2.0
Average	87.6	1.8
Standard deviation	1.7	0.2

weather and climate services was estimated to be about 324 times per year. The annual costs of accessing these basic public weather and climate services per firm were estimated to be about A$308 annually based on the unit access cost of about A$0.95. Hence as a rough guide, for the mining industry, the societal benefit–cost ratio was about 17.4 (i.e. 5346/308). Since the basic public weather and climate services are used by all sectors of the Australian economy in addition to being used by households as consumption goods, the benefit–cost ratio estimated in this study reflected only the situation for the mining industry. Similar studies are needed in all industries that use public weather and climate services to aggregate the WTP across industries, so as to establish the societal benefit–cost ratio of the basic public weather and climate services when they are used as inputs in production processes. When combined with the value of these services when they are used as consumption goods (for which a study has been conducted for the Sydney metropolitan area), the total societal economic value of the basic public weather services for the entire economy can then be derived.

The three most frequently mentioned weather adverse elements were heavy rainfall, tropical cyclones and high speed winds. The three frequently mentioned important sources of weather and climate information to combat adverse impacts were the mining firm's own weather recording station and/or instruments, followed by the mass media (television, radio and newspapers) and direct contacts with offices and stations of BoM. About 38% of firms required more specialist weather and climate information from BoM (beyond that of the basic public services). One-quarter of those requesting specialist information indicated that they needed more detailed information on the tracking and warnings related to tropical cyclones activities. The need for more locality-specific weather reports containing details of severe weather events was the next most important additional information sought. This was also indicated by 25% of respondents requesting specialist weather and climate information. Not surprisingly, a majority of non-users of public weather and climate services indicated that the public weather and climate services were too general, covered much larger geographical areas, and were not specific enough for their day-to-day activities and/or for protection against severe weather events. For further details see Anaman & Lellyett (1997).

8. Evaluation of the effect of tropical cyclone warnings on the incomes of hotels along the Queensland coast

This study considered the effect of overwarnings issued about tropical cyclones on the revenues of hotels operators. The costs of overwarning due to inaccurate forecasts is considered an important component of the costs of tropical cyclone warning service (TCWS). The impact of TCWS on hotel gross revenues was investigated using several econometric models for nine different regions of the Queensland coast based on time-series and cross-sectional data from 1986 to 1993. The results confirmed that there was a significant relationship between cyclone incidence and warnings and the gross income of hotels in the Middle and Northern sections but not in the Southern section of the Queensland coast. A significant relationship was confirmed in at least one of the two econometric models with the best fit for Maryborough, Bundaberg, Rockhampton, Mackay, Townsville and Cairns. For the remaining three of the nine primary regions, Gold Coast, Sunshine Coast and Whitsunday, the relationship was not confirmed.

The economic loss for hotels caused by cyclone incidence and warnings was estimated to be about A$3 million per year. However, the economic loss attributable to the cyclone season, as compared with the non-cyclone season, was about A$55 million per year. The influence of the cyclone season thus appeared to be about 18 times as important as actual incidence of cyclones and warnings in explaining the variation of hotel incomes. Cyclone season was a complex variable that captured

impact of rainfall and other factors in addition to the perceived risk of cyclones to potential tourists. The yearly impact on average gross incomes of hotels along the Queensland coast due to the cyclone season was about 10% of the yearly gross income, while the corresponding effect attributed to the actual cyclone incidence and warnings was only about 0.5%. Therefore, the fact that the variable capturing both actual cyclone incidence and related cyclone warnings in the area had a very small influence on gross incomes of hotels indicates that the effect of cyclone warnings issued by TCWS (which included overwarnings) was relatively very small. The cost of overwarnings about tropical cyclones appeared not to be a serious economic problem for tourism industry. For further details see Drake (1995).

9. Benefits homeowners in cyclone-prone areas of Queensland derive from the tropical cyclone warning service

Tropical cyclones have a significant economic impact in northern Australia and are one of the most economically significant natural disasters responsible for the highest insurance payouts. The Insurance Council of Australia indicated that the average cost of tropical cyclones in terms of insurance payouts was about A$75 million over the 20-year period from 1970 to 1989. The total net costs of tropical cyclones to the public have been estimated to be about four times as large as insurance payouts by the Insurance Council of Australia, suggesting that the average annual total costs could be about A$300 million (Joy, 1991). The tropical cyclone warning service (TCWS) produced by BoM has changed conditions for people in disaster-prone areas such as the tropics. However, there have been few economic impact studies of the TCWS in Australia.

9.1. Contingent valuation study of the benefits of TCWS

This study involved a survey of homeowners to establish the economic benefits that they derive from the TCWS. This survey used the contingent valuation method which gave theoretically correct welfare measures of the benefits of the service. The contingent valuation method involved two separate components:

(a) the estimation of the benefits based on what homeowners are willing to pay (WTP) to have access to TCWS; and
(b) the amount that homeowners are willing to accept (WTA) to be without TCWS.

In the case of the WTP approach, the contingent valuation method would measure the so-called compensating variation. In the case of willingness to accept (WTA) approach, the method would measure the so-called equivalent variation (see Hanley *et al*., 1997). These economic estimates would include all benefits homeowners believed they would get from the TCWS, which would include reduced threat to personal safety, reduced risk of loss of property and improvement in wellbeing from reduced risk of being surprised by tropical cyclone events.

The survey also requested answers from homeowners on a few questions of their experience with tropical cyclones and their degree of worry that their neighbourhood would be hit by a cyclone. Information about the extent of damage to property and risk of life for normal and severe tropical cyclones was given together with probabilities of different categories of cyclones hitting a particular city. Respondents were also asked about their prediction of financial loss in case their neighbourhood was hit by normal and severe tropical cyclones, and the proportion of the loss that would be covered by insurance payouts. They were then requested to indicate the maximum amount that they would be willing to pay in the form of *an extra Federal income tax* just for financing the TCWS, given the option that the service would cease to exist without the payments. About 56% of respondents indicated that they would not be prepared to pay for the service. The mean annual WTP, excluding the deemed protest zero-bids, was A$32 in Brisbane, and A$52 in both Mackay and in Townsville.

9.2. Willingness to accept amounts of money to be without TCWS

A question about the amount respondents would be willing to accept (WTA) to be without the TCWS was also included in the Mackay and Townsville surveys. The WTA format gave property rights to respondents since they were hypothetically compensated if they chose to lose their rights of being warned. The bids derived from the WTA question were also not constrained by the incomes of individuals as applicable to the corresponding WTP question. Not surprisingly, a much larger proportion of respondents gave non-zero bids to the WTA question than for the WTP question. People seemed to find it easier to accept the idea that they had the right to being warned about tropical cyclones and therefore be compensated if they were to lose those rights. Because of the extreme bids, the median value probably reflected the average value of the service better than the mean value. The median annual WTA was A$200. It was quite clear, from the high degree of protest zero bids in stating their WTP amounts of money combined with very high WTA bids, that many people did not accept the idea that it was possible to put a price on the TCWS. Respondents seemed to believe that it was the duty of Government to produce and finance a reliable TCWS.

The population along the Queensland coast is currently about two million, and is increasing by 2–3% per

Table 5. *Users' perceived quality of meteorological services in terms of average numerical ranking of economic quality attributes of information*[a]

Quality attribute of information	Cottonfields Weather Service (New South Wales)	Public weather service for Sydney householders	Public weather and climate services for Queensland mining firms
Ease of understanding	4.3	4.2	3.8
	(0.12)	(0.17)	(0.17)
Overall usefulness	4.2	3.8	2.8
	(0.14)	(0.20)	(0.37)
Relevance	4.1	4.0	3.3
	(0.15)	(0.24)	(0.20)
Adequate level of details	4.1	—	3.5
	(0.15)		(0.21)
Timeliness	3.9	—	—
	(0.13)		
Accuracy	3.6	3.2	3.2
	(0.14)	(0.25)	(0.22)
Frequency (time of day)	3.5	—	—
	(0.23)		

[a] 5, the highest score, was used to denote that the information was considered excellent while 1, the lowest score, meant information provided was regarded as very poor. Scores of 4, 3, 2 indicated good, satisfactory and unsatisfactory assessments respectively. The coefficients of variation of the scores (defined as the mean score divided by the standard deviation) are in the brackets.

annum. With a conservative average annual WTP for access to the TCWS of about A$30, about two-thirds of people owning their homes, and adjusting for about 50% of the population over 18 years of age old, the aggregate annual WTP of homeowners for access to the TCWS would be about A$20 million. The annual costs of the TCWS is about A$2 million, indicating a positive benefit–cost ratio to society of about 10:1. Using the WTA estimate of A$200 would result in a benefit–cost ratio to society of about 66:1. For further details see Drake & Eriksson (1997).

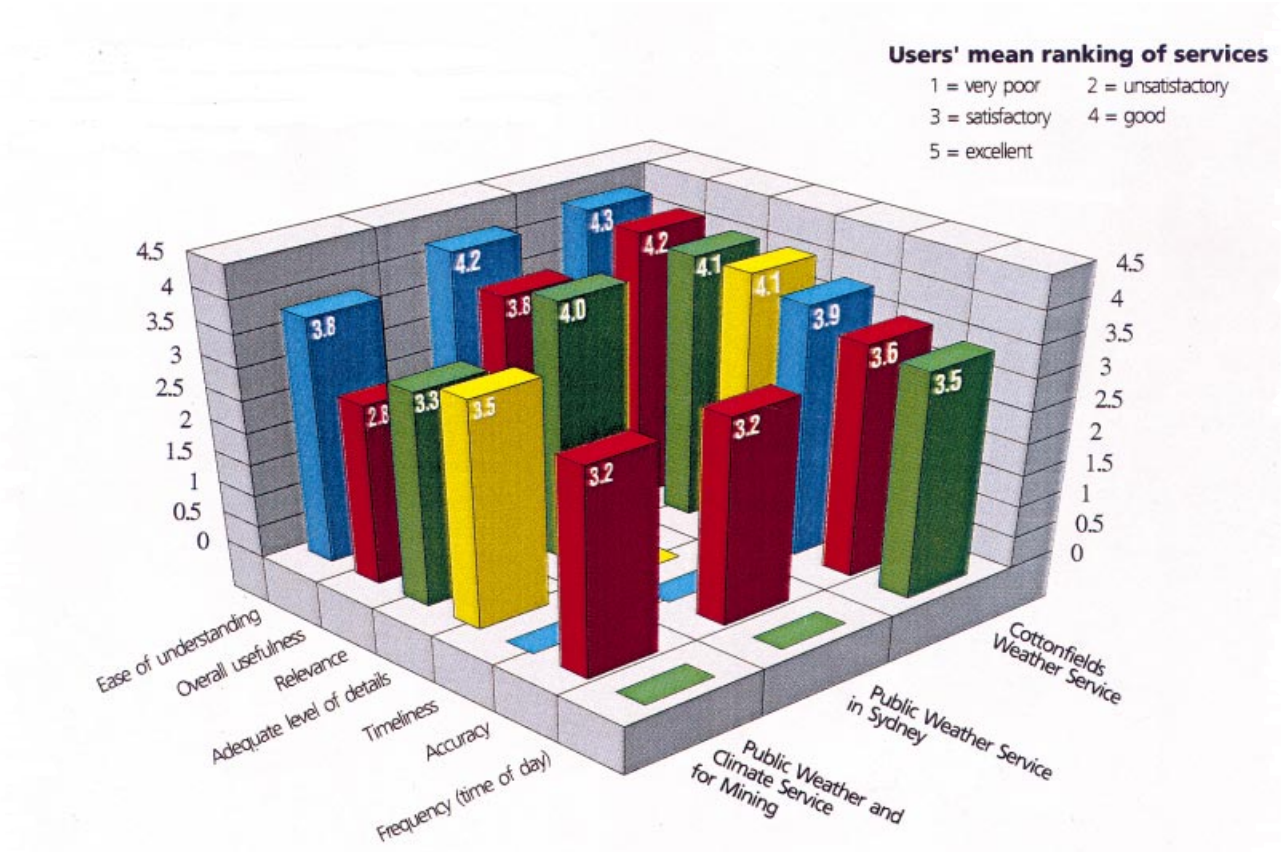

Figure 4. *Graphical representation of users' perceived quality of meteorological services in terms of average numerical ranking of economic quality attributes of information.*

10. Discussion

Table 5 and Figure 4 provide a summary of the economic quality attributes of selected meteorological services determined through surveys (subprojects 1, 2 and 5). The ease of understanding of information was ranked as the highest valued attribute. Not surprisingly the benefit–cost ratios of the services were high partly because, in the first place, users understood the messages contained in the information. The specialist weather service for the cotton industry was regarded as of the highest quality product because of the enhancement of the general public weather service for explicit needs of cotton growers. Accuracy was generally considered satisfactorily with average ranking always above the satisfactory level of 3.0. The accuracy of the enhanced specialist weather service was also ranked higher than the public weather services. In the specific case of use of public weather and climate services by the mining industry in Queensland, all quality attributes of information were ranked well except the overall usefulness. One-third of users considered the services to be too general and half of those firms (which considered the services too general) wanted enhanced weather services similar to Cottonfields Weather Service developed for the cotton industry based on similar producers' requests. As shown in Table 6, the benefit–cost ratios of the services were high, reflecting partly on their high quality indicated by the attributes of information.

The two aviation subprojects 3 and 4 used different economic methodologies and did not involve direct surveys to elicit the quality of the services from users. Subproject 3 was based on a simulation modelling analysis incorporating the cost–loss ratio technique, using TAF data over the period 1972 to 1993 to estimate the net direct economic benefits to Qantas Airways Limited, and using TAF information for 1993 economic conditions. The net direct economic benefits were derived in terms of expected fuel savings less increased labour and other costs associated with diversions caused by inaccurate TAFs and were applicable strictly for Sydney International Airport. This study concluded that the net direct economic benefits of TAF information to Qantas was about A$6.9 million for 1993. When this result was extended Australian-wide, the net direct economic benefits of TAF information were about A$16.0 million, for international flights based on Sydney accounting for about 43% of all Qantas' international flights to Australia. This extension of the result could be justified because of similar TAF accuracy figures for the four main Australian airports (Brisbane, Melbourne, Perth and Sydney) over the 1972 to 1994 period (see Anaman *et al*., 1997).

Subproject 4 used another approach to determine the economic benefits of the fuel policy change involving TAF information for Qantas, based on published annual reports and econometric time series analysis for international flights using global data. The annual fuel savings was estimated to be between $A27 and A$42 million for 1993/94 economic conditions. In order to compare the result of subproject 4 with that of subproject 3, the equivalent annual benefit from use of TAF information by Qantas solely for Australian international airports was derived. This was based on Qantas' flights to Australia accounting for about 40% of all its international flights before the merger with Australian Airlines in the 1992/93 financial year. The equivalent annual fuel savings from use of Australian-based TAF information were about A$16.8 million (i.e. 0.40×A$42 million) for the 1993/94 financial year.

Table 6. *Estimated benefit–cost ratios of selected meteorological services produced by the Australian Bureau of Meteorology*

Meteorological service	Benefit–cost ratio	Remarks
Basic public weather services for householders (forecasts and warnings)	4:1	Excludes the benefits from use of basic public weather services as inputs in the production processes of business firms and organisations.
Cottonfields Weather Service for cotton producers in New South Wales and Queensland	12:1	Benefit–cost ratio is based on the reduction in the unit cost of production of cotton from the use of the service.
Terminal aerodrome forecasts service for international flights to Sydney international airport (for Qantas Airways Limited)	2.7:1	Benefits mainly in terms of fuel savings less the cost of diversions from inaccurate forecasts. The ratio is strictly a financial benefit–cost ratio for Qantas Airways Limited.
Terminal aerodrome forecasts service for international flights to all Australian international airports used by Qantas Airways Limited	1.8:1 to 2.8:1	Benefits due to fuel savings. The ratio is strictly a financial benefit–cost ratio for Qantas Airways Limited.
Public weather and climate services for mining firms in Queensland	17:1	
Tropical cyclone warning service for homeowners in Queensland	10:1 to 66:1	Benefit–cost ratios are preliminary figures.

Thus, the comparable maximum Australian-based benefits derived from subproject 4 were almost equal to the net direct economic benefits applicable to Australian-based international flights inferred from subproject 3 (A$16.0 million). Subproject 4 did not include the costs of diversions due to inaccurate TAF information (such as increased labour costs and overheads), which should be subtracted from the fuel cost savings to arrive at net direct benefits to the airline. However, this subproject also did not incorporate the possibility of increased payload due to carrying of less fuel, a source of additional revenue. Thus, it appeared that net direct benefits of use of TAF information derived from both subprojects 4 and 3 were likely to be similar, considering that diversions due to inaccurate TAFs were about 1% or less with the introduction of the Code Grey Warning Service in 1991 to improve quality control of TAF information.

Subprojects 6 and 7 were concerned with the evaluation of the tropical cyclone warning service in Queensland. Subproject 6 involved the use of econometric analysis of incomes of hotels to establish whether warning information about tropical cyclones had a negative effect of incomes of hotels. Tropical cyclone warning information was shown to have insignificant negative effect on the incomes of hotels. The estimation of the benefits homeowners derived from the tropical cyclone warning service was undertaken using the contingent valuation method (subproject 7). The results indicated that homeowners placed a high value for the service and were prepared to pay on average at least A$30 annually for the service (rather than be without it). Overall, based on the results from this study and the evaluation of the basic public weather service in Sydney (subproject 1), the contingent valuation method was found to be a useful tool to elicit the economic value of meteorological services when used as consumption goods by householders. The results of these studies tended to show that the economic value of these services was related to socio-economic characteristics consistent with economic theory of demand of goods and services.

11. Conclusions

This report is a summary of the methods and findings of a research project undertaken to evaluate the economic and social benefits of meteorological services in Australia. The services evaluated were the basic public weather services and several user-pay services used by business firms in several sectors of the economy. The results indicated that benefit–cost ratios of the meteorological services were high. It was not possible to determine the overall benefit–cost ratio of all BoM's services because only a limited number of important services provided by BoM were evaluated. The economic value of the basic public weather services, when used as a consumption good by householders expressed as the average annual WTP for the service, was estimated to be A$24 per adult. The public component cost of BoM (total expenditures minus revenues raised) was A$13.2 per taxpayer for the 1994/95 financial year. Hence the *minimum* societal benefit–cost ratio for BoM as a whole was about 2:1, *when only the householder benefits of the public weather services were used to derive the benefits component of the ratio*.

The benefit of use of improved weather forecasts in the form of terminal aerodrome forecasts by Qantas Airways Limited for international flights to Australia was estimated to be at least A$16 million per year. The use of enhanced weather information led to about one per cent reduction in the cost of producing cotton in New South Wales. Two studies were undertaken on the evaluation of the tropical cyclone warning service in Queensland for tourism industry (hotels) and as provision of information for homeowners respectively. Warning information about tropical cyclones including possible over-warnings appeared not to have negative effect on incomes of hotel operators, contrary to popular perceptions obtained from the mass media during some cyclone seasons. However, the tropical cyclone service was regarded as valuable by homeowners with a conservative average annual WTP for the service being A$30.

The quality of the services measured by various attributes of ideal quality information was generally high. The quality of the services was considered high principally because a key attribute of ideal information – ease of understanding – was ranked highly and it was consistently ranked as the number one attribute. This meant that users adequately understood the messages contained in the information. Accuracy was an attribute where users indicated that some modest improvement was needed, even though overall the average ranking of this attribute was considered satisfactory. Another finding was that the basic public weather services were regarded as too general when they were used as inputs for production purposes for mining in Queensland. Specialist enhanced forms of the public weather services were therefore needed to be produced to satisfy growing demand for such services from the mining industry and potential users from other sectors. An extension of the current study could be the evaluation of use of improved weather information by the coal-fired electricity generation industry (a major emitter of greenhouse gases) to reduce emission of greenhouse gases to meet Australian targets under international climate change conventions. It was shown that use of improved weather information by Qantas Airways Limited led to about 6% reduction in consumption of aviation fuel equivalent to over 300 000 tonnes of reduced CO_2 emission annually.

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